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Ferro-alloys and their effect on steel in the German war eco. 1943-44.

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FOREIGN ECONOMIC ADMINISTRATION
European Enemy Division

# FERRO-ALLOYS AND THEIR EFFECT ON STEEL IN THE GERMAN WAR ECONOMY, 1943 AND 1944

CONFIDENTIAL

January 24, 1944

G-0877-C-nebu

## Conclusions

Germany entered 1944 with virtually no stocks of any major ferro-alloy, with the possible exception of manganese. Of the major ferro-alloys, only vanadium might be produced in Germany proper in sufficient quantity to meet war requirements, and even this at the cost of lowered steel production. Domestic production of manganese might amount to 20 percent and the output of nickel and tungsten to only five or six percent of war requirements. The production of cobalt is negligible, and there are no chrome or molybdenum deposits within German borders. To maintain its alloy steel economy, Germany is therefore dependent upon current supplies from outside of Germany. Because many of these sources are located at the extreme limit of German control or in neutral countries, effective military and economic warfare measures can decisively alter the German position in ferro-alloys in 1944.

Engineering, or ordnance steels, which constitute 92 percent of Germany's alloy steel output, would be most seriously affected by the loss of the two major ferro-alloys, manganese and chrome. The loss of manganese from Nikopol would be a heavy blow to the German steel economy, though the effect will not be immediate because of available stocks and current production of manganese in Enemy Europe. If, in addition, however, the chrome supplies from Turkey and the Balkans were cut off, the German alloy steel economy might break down completely.

Cobalt and nickel from Finland and molybdenum from Norway, although available only in extremely limited quantities, are important to the Germans. The elimination of these sources would be reflected in an almost immediate deterioration of quality in many specialized ordnance materials, which do not involve a very large tonnage but which are nevertheless vital to the German war economy.

An interruption in the flow of tungsten from Spain and Portugal to Germany would ultimately lead to a sharp curtailment in the production of high-speed steels and die castings as well as tungsten carbide, and may make impossible the production of carbide cores for armor-piercing projectiles.

However, the German war economy will not collapse immediately upon the loss of the major ferro-alloys, because as the war situation becomes critical, Germany can resort to the exhaustion of the so-called "pipe-line reserves," using up every available ton of supplies within the country. Moreover, Germany will benefit by the lag factor. Because of the pipe-line reserves and the lag factor, 6 to 9 months may elapse before the interruption of the flow of ferro-alloys to Germany from occupied or neutral countries is likely to be reflected in the output or quality of ammunition or other war materiel.

Even before the war, in an effort to become self-sufficient, Germany practised stringent economy in the consumption of ferro-alloys. The practice spread during the war and finally, with the introduction of the so-called substitute steels, more or less equivalent to the United States National Emergency Steels, affected all steel makers. The formulas of these steels, which assured the presence of steel properties requested by Ordnance, utilized to the utmost the alloy power of the various alloys. In Germany, as in the United States, the emergency steels are not inferior in quality to prewar steels which consumed much larger quantities of ferro-alloys.

In spite of the economical use of alloying elements and the practice of substitution, the limited available supplies of virgin alloys would have been inadequate if Germany had not requisitioned all supplies of alloy scrap.

Germany also controlled the mine output of all occupied countries, requisitioning supplies, expanding production as much as possible, and repairing destroyed or neglected pits and installations. It received ferro-alloy ores from certain neutral countries. As a result, German supplies of virgin ferro-alloys in 1943 were as follows:

**Germany: Current Ferro-Alloy Supplies, 1943**
(in metric tons of contained metal)

| Ferro-alloy | From occupied countries | From neutral countries | Domestic production | Total a/ supplies |
|---|---|---|---|---|
| Manganese | 300,000 | - | 50,000 b/ | 350,000 |
| Nickel | 6,000 c/ | - | 1,000 | 7,000 |
| Chromium | 33,000 | 12,000 | - | 45,000 |
| Molybdenum | 650 to 700 | - | - | 650 to 700 |
| Tungsten (concentrates) | - | 3,100 | 200 | 3,300 |
| Vanadium | - | - | 1,000 d/ | 1,000 |
| Cobalt | 125 to 175 e/ | - | 125 | 250 to 300 |

a/ In addition, Germany had some stocks from 1942--about 4,000 tons of chromium, 200 tons each of molybdenum and vanadium, and 250 tons of tungsten.
b/ Highest estimate.
c/ 3,500 tons from Finland.
d/ Some of the vanadium was obtained in Belgian steel plants.
e/ Finland.

Except for molybdenum and nickel, Germany's ferro-alloy supplies were probably sufficient to satisfy requirements in the production of over four million tons of alloy steel in 1943. However, the pattern





used in the United States for engineering steels demonstrates that a balanced system in these steels calls for the application of four alloying elements--manganese, chromium, nickel, and molybdenum. Germany was not able to maintain such a system in its engineering steels, and probably either shifted or was on the verge of shifting sometime in 1943 to a two-alloy pattern, based on chromium and manganese, which could be more readily disrupted than a four-alloy pattern. Whether the shift to a two-alloy pattern has already taken place cannot be proved empirically, because there are as yet no analyses of captured materiel manufactured in 1943. But even if 1943 materiel were found to contain, in addition to manganese and chromium, some small amounts of nickel or molybdenum, they would probably represent residuals from scrap recovery, rather than virgin alloys intentionally introduced in the steel.

In 1943, German steel output amounted to 35 million tons, of which over four million tons were alloy steel. During 1944 steel production may decline considerably. The reoccupation of France, Belgium, and Luxembourg would cut German supplies of iron ore in half and lower total steel production by about 25 percent. The halting of Swedish exports of high-grade iron ore would cause an additional cut of about 25 percent. The bombing of plants and transportation centers may play an important role in still further reducing German steel output. However, as long as Germany can obtain supplies of chromium and manganese, the tonnage of alloy steel produced will probably remain in the neighborhood of four million tons.

If direct military action or economic warfare measures succeed in cutting off cobalt and nickel from Finland, molybdenum from Norway, and tungsten from the Iberian Peninsula, the German alloy steel economy will be most seriously affected. Even more important, should manganese from Nikopol, as well as chrome from Turkey and the Balkans be lost to Germany, its alloy steel economy will collapse completely within 6 to 9 months.

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## I. INTRODUCTION

Possible territorial changes in 1944 may have a much more pronounced effect on German supplies of ferro-alloys than on those of iron ore. The chief sources of iron ore, Germany proper and the Lorraine basin, are, for the present, secure. The second largest source, in Sweden, may be less secure, though not actually threatened. The sources of alloying elements, on the other hand, situated, with one or two exceptions, on the fringes of Europe, are much more open to attack.

The analysis made in this report of Germany's supply position in ferro-alloys is based on the interrelation of the ferro-alloys and their effect upon the alloy steel production in the German war economy. Such a survey would have been difficult to conduct at the beginning of the war when Germany had at its disposal impressive stocks of raw materials and huge quantities of stored ammunition, when the Germans had not yet digested the immense loot from neighboring countries, and when captured materiel was scarce and not available for analysis. At the present time, however, with a relatively stabilized economy in Enemy Europe, and with the crucial year 1944 just beginning, an overall survey of the German alloy steel position seems practicable.

In the absence of exact information concerning the amount of alloy steel produced in Germany, the pattern of steel production in the United States and, to a smaller extent, that in Great Britain, has been used as a working basis, to be modified in the light of known German conditions. Such procedure seems justified by the fact that the Germans themselves recognize the close similarity of at least some American steels to respective German types. This conclusion was reached by the German Aeronautical Research Institute in a report on the engine construction of American, British, and French planes shot down inside Germany in the first two years of the war. These planes were subjected to a metallurgical analysis, with the result that the German application of alloys was found to correspond more closely to that of the United States than to that of Great Britain. 1/

1/ The British steels were declared to contain more alloying element than German standard for the same stressing would allow. See The Iron Age, December 25, 1941, pp. 33-40.

## II. FUNDAMENTALS OF MODERN ALLOY STEEL METALLURGY

### Composition of Alloy Steels

Alloy steel is the keystone of a modern war. A country whose plants could produce only carbon steel and whose ammunition, tanks, and aircraft contained no alloy, could not resist indefinitely an enemy equipped with tools and weapons made of alloy steel. The success of all weapons, offensive as well as defensive, is to a large extent dependent upon the use of alloy steel superior in performance to that of the enemy. The great complexity of elements in modern war equipment is exemplified by the alloy analysis of a German projectile selected at random (see Table 1).

TABLE 1

Analysis of Metals Used in German 8.8 cm. Projectile
(Armor-Piercing Round, Nose Cap of a Shell)

| Element a/ | C | Mn | P | S | Si | Ni | Cr | V | Zr b/ |
|---|---|---|---|---|---|---|---|---|---|
| Percent of contained metal | .59 | .70 | .015 | .025 | 1.45 | .61 | .60 | .12 | .09 |

Source: Examination of Enemy Materiel: A Metallurgical Examination of Two German 8.8 cm. High Explosive Shells, National Defense Research Committee, War Metallurgy Division, August 14, 1943, p. 8.

a/ The elements represented by the symbols are, in order given: carbon, manganese, phosphorus, sulphur, silicon, nickel, chromium, vanadium, and zirconium.
b/ The analysis also showed the presence of insignificant amounts of tungsten, molybdenum, copper, aluminum, titanium, and tin. In addition, the report stated that "The amount of boron shown, 'less than 0.01 percent', merely means that absence of boron was not proven; it does not mean that boron was present." (p. 3).

Every addition of a new element, even to the extent of only 0.12 percent (vanadium), as shown in Table 1, affects the properties of the final product, either by strengthening some reactions or by neutralizing others. Such reactions have been subjected to hundreds of tests in laboratories and factories, and probably years of experimenting gave sanction to the steel composition of this projectile.





Some ferro-alloys have a long history. To cite but one example: The Toledo swords and arms, famous throughout many centuries, owed their strength and flexibility to the addition of small amounts of tungsten and manganese to the ordinary Spanish carbon steel. Some other alloys, such as vanadium, are of recent date. The transition from carbon steel to ternary or more complex alloy steel in the manufacture of war equipment has been gradual, and the composition of alloy steel used for this purpose has gradually changed with time and accumulated experience. What is more important, in the last decade substantial changes have been made in the application of different alloying elements.

To be adopted for manufacture after its utility has been demonstrated, each alloy has had to meet the competition of other alloys in several respects--price, availability, ease of treatment, complexity of equipment required, and the number of man-hours and amount of electric energy consumed in its production. Once adopted, an alloy is usually continued in use until scarcity or new experimentation or both introduce a new alloy steel to the steel industry.

### Unique Properties of Various Alloys

This report is chiefly concerned with only the most important steel-making ferro-alloys--manganese, chromium, molybdenum, nickel, silicon, tungsten, cobalt, and vanadium. A few minor alloys, such as titanium, boron, or zirconium, are also considered briefly.

Each alloying element has distinct characteristics and imparts to the steel specific and individual properties if applied within the well-defined limits of an established heat-treating schedule.

Chromium in small quantities accounts for strength, wear resistance, and hardenability of steel, and in large amounts provides resistance to corrosion and oxidation. Manganese in small amounts improves the rolling and forging qualities of steel, neutralizes sulphur, and increases strength. In large amounts it increases the resistance of steel to abrasion. Tungsten and vanadium are strong carbide-forming agents; in addition, tungsten provides the red hardness of steel, while vanadium controls the grain size and makes the steel tough and resistant to repeated shocks. Molybdenum improves the strength of steel and is indispensable in making certain creep resistant steels. Nickel increases the tensile strength and toughness and in large amounts also the corrosion resistance of steel. Cobalt is almost unique in bonding tungsten

carbide. Silicon, within limits up to .30 percent, is used mainly as a deoxidizer. It also increases the tensile strength of steel.

On the whole, alloying elements make steel stronger and more ductile, refine its grain, counteract the effects of oxides and gases, eliminate impurities, and raise resistance to corrosion, abrasion, fatigue, or wear. These effects, however, are achieved only when alloying elements are applied in the proper way. The amount to be added may range from as little as 0.001 percent for boron 2/ to as high as 28 percent for chromium, or 18 percent for tungsten. If the proportion is violated, the same alloying metal may produce harmful results. For instance, an increase of boron content over 0.01 percent impairs the forging qualities of steel and makes it less tough. Raising the chromium content beyond four percent increases the strength but decreases the toughness of high-speed steel so that another element must be added.

Furthermore, none of the alloying elements is fully effective if used by itself. In addition to manganese up to 0.6 percent, which is essential in ordinary, or carbon, steel, a combination of at least two elements is required. Actually, three or four alloys are needed to assure the greatest alloy efficiency in a steel. For instance, the hardenability effects of several elements multiply each other while increased amounts of one element are less than additive.

## Interchangeability of Alloys

Insofar as their properties coincide, the alloying elements can to some extent replace each other. For instance, hardenability can be achieved by the addition of a specified amount of manganese, chromium, molybdenum, or nickel. Resistance to corrosion can be assured by chromium and increased by nickel. Greater tensile strength can be reached through the addition of manganese, plus chromium or molybdenum, or certain other alloying elements.

Equivalent "hardenability" effects in alloy steel can be obtained if, for every .8 percent of manganese in excess of the manganese contained in carbon steel, other elements are substituted

2/ Some alloying elements, such as boron, titanium, and zirconium, are added to steel in extremely minute quantities. In metallurgy, these elements are called "additive agents." Their importance should not be underestimated, as they are frequently used in the absence of major alloying elements. When additives are used, a smaller percentage of major alloying elements is required. However, as they are probably used to about the same extent in the United States and in Germany and as both countries at present have an adequate supply, they will not be considered separately in this report. The final calculations are not affected by their omission.





at the following rates:

| | | | | | | |
|---|---|---|---|---|---|---|
| | .32 | of one percent | of | contained | chromium | |
| or | .15 | " " | " | " | " | vanadium |
| or | .24 | " " | " | " | " | molybdenum |
| or | 1.0 | percent | | " | " | nickel |
| or | 1.15 | of one " | | " | " | silicon |

In other words, roughly 32 pounds of chromium, 24 pounds of molybdenum, 100 pounds of nickel, or 115 pounds of silicon can be used to replace 80 pounds of manganese.

The alloys, however, are not completely interchangeable. Steel-makers know that differences resulting from the use of different alloy metals can be influenced by such factors as variability in the heat treatment, the forging and quenching temperatures, the kind of tools used and their handling.

The range of interchangeability of alloying elements is wider in low-alloy steels and narrower in high-alloy steels. Little substitution is possible in high-speed steels, and there is no substitute for chromium in stainless steels.

## Use of Scrap in Making Alloy Steel

In the manufacture of steel by the open-hearth process much use is made of scrap, a large part of which originates in the steel mill itself. Broadly, half the charge of open-hearth furnaces is scrap, and half of it comes from the circulating load of croppings, skulls, and clippings of the steel mill. Even in peacetime, alloy steel scrap was used to effect a saving in the consumption of virgin alloy metals. This universal metallurgical practice has grown in importance since the beginning of the present war, as the steel industry has had to cater to an ever-increasing demand for steels of specified qualifications in spite of the deficiency in some important ferro-alloys and unstable supplies of others. The importance of scrap can be seen from the following example: 1,000 lbs. of new nickel applied in making 3.5 percent nickel steel will produce 12.8 tons of nickel-bearing ingots, if new nickel only is employed; whereas, 22.8 tons, or almost double the amount, can be produced from 1,000 lbs. of new nickel if the steel plant reverts scrap and also uses the scrap recovered during the finishing operations. About the same relative increase in the tonnage of alloy steel ingots could be obtained from molybdenum, tungsten, or cobalt by the use of scrap, as these elements are not oxidized in steel-making and thus the percentage of recovery is high. Vanadium and chromium,

because of oxidation during the steel-making, have a lower recovery than those elements previously mentioned unless special processes are used for reclamation. In the United States, 52 percent of the nickel, 34 percent of the chromium and 44 percent of the molybdenum consumed come from scrap.

## Different Types of Alloy Steel

Engineering steels. The largest consumption of ferro-alloys is in engineering steels, utilized mostly for ordnance purposes, in transport equipment, and in structural work. The alloy content of these steels is ordinarily not over two percent and seldom more than five percent, but their total tonnage is large; they constitute about 92 percent of all alloy steel made in the United States. The percentage of engineering steels produced in Germany is assumed to be approximately as high.

No direct information is available on the tonnage of various ferro-alloys consumed in the production of engineering steels in Enemy Europe. However, a convenient yardstick is provided by the experience of metallurgy in the United States, where tremendous strides have been made during the present war in the utilization of available alloying elements to the limit of their potential power. Such advances are also assumed for Germany.

To measure the ultimate potentialities which can be realized through the application of the most essential ferro-alloys, A. B. Kinzel, one of the world's leading metallurgists, suggests the use of the concept "alloy power". By his definition, alloy power is a measure of the effect produced by alloying elements added to steel in specified quantities and under a specified heat treatment which assures sufficient cooling to give a uniform microstructure to the steel, so that the maximum strength and ductility are attained. The unit of alloy power here chosen is the alloy effect required to produce in a steel bar 1.75 inches in diameter the same properties of strength and ductility that could be obtained in a one-inch bar, with the same heat treatment, but without that alloy in the steel. Thus, by utilizing completely the potentialities of ferro-alloys, steel shapes of larger sizes can be given the desired hardness and toughness and can be made to retain them better, with the identical heat treatment given to smaller shapes of carbon steel.





Table 2 shows the alloy power used in the United States for each 1,000 tons of engineering steels to produce maximum strength and ductility. In general, the various alloying elements can be interchanged quantitatively as long as there is a combination of at least two ferro-alloys. For instance, four units of nickel, 3.2 units of manganese, 1.28 units of chromium, or 0.96 units of molybdenum can be substituted for each other as available.

TABLE 2

United States: Alloy Power Used per 1,000 Tons of Engineering Steel a/

| Alloy | Alloy power (units) | Hardenability factors | Amount of alloy (tons) |
|---|---|---|---|
| Manganese | 13.8 | 0.8 | 11.0 |
| Molybdenum | 5.4 | 0.24 | 1.3 |
| Chromium | 18.4 | 0.32 | 5.8 |
| Nickel | 4.0 | 1.00 | 4.0 |
| Total | 41.6 | -- | -- |

Source: Calculated on the basis of United States war consumption of ferro-alloys in engineering steels.

a/ This estimate is made on an "ingot-alloying element" basis; i.e., the amounts given are of virgin alloy metals only, the normal alloying content provided by scrap being assumed. In the United States, the units given in this table are comprised in steels containing more than one percent of manganese or .30 to .40 percent of nickel or chromium.

This pattern of production of engineering steels was followed in the United States during the last quarter of 1943 when the greatest care was being exercised to utilize the maximum power of ferro-alloys. However, it is not a rigid pattern, and it is conceivable that in some months smaller proportions of ferro-alloys were consumed than in others. Though it does not offer a precise evaluation of the tonnage of the various ferro-alloys used, this estimate does establish the order of magnitude in which they are used. It is not applicable to either stainless or tool steels.

Stainless steels. The stainless steels are used mainly in the chemical industries and in aircraft motor parts, because of the need for resistance to corrosion, resistance to very high temperatures, or other special characteristics. The average alloy content of these

steels is around 20 percent, although about two-thirds of all stainless steels have an alloy content up to 25 percent. In the United States, the stainless steels constitute about 2/3 of one percent of the total steel output, or about five percent of total alloy steel. As Germany has a highly developed chemical industry and produces large amounts of synthetic rubber, oil, and fibers, its needs for stainless steels must be at least proportionately equal to those of this country. The United States ratio of stainless steels to total steel will therefore be accepted for Germany. Should, however, such elements as nickel and chromium, indispensable in making stainless steels, become critically short in Germany in 1944, the ratio will be lowered somewhat, to perhaps 0.5 percent of the total steel output.

Tool steels. There are two groups of tool steels: 1) low-alloy steels which normally have less than two percent of alloy content but may have up to six percent, and 2) high-speed steels and die steels, having a range of alloy content from 6 to 24 percent. In 1942, the United States industry went through a period of intensive retooling during which the yearly output of tool steels amounted to about 140,000 short tons in each group. In 1943, the high-speed steels amounted to about one percent of total alloy steel output, and they will range between 0.5 and 0.6 percent of the total in 1944, when the output is expected to be only about 70,000 tons of high-speed steels and about 120,000 tons of other tool steels.

The German industry had been thoroughly retooled before the war and did not need to undergo fundamental conversion as did the United States industry. On the other hand, the wear and tear on the old German tools and machinery must have been very great, and with a number of plants bombed out of operation, there is need for new installations and tools. Some obsolete equipment may require redesigning. There must also be a recurrent demand for retooling in those plants operating 24 hours a day, in which the machinery is subjected to almost constant use, and in which the heterogenous workers of various nationalities and backgrounds possess different degrees of adaptability and skill in handling the tools.

Furthermore, Germany is using plants and workshops all over Europe for the production of war equipment on German account. Their installations and tooling equipment had to be adjusted to German needs, which meant a demand for more tool steels. France, for example, formerly produced only 20 percent of the tools required by its industries, the rest being imported from the United States,





Great Britain, and Germany. The tool conversion of French plants to production on German account must have been carried through by Germany.

In view of these factors, and allowing for some tool destruction by bombing, the demand for tool steels, including carbide tools, in Germany may be expected to be in the same proportion to total steel requirements as in the United States. It would seem reasonable, therefore, to estimate the German output of high-speed tool steels at about 0.7 to 0.8 percent of the total alloy steel, or at about 35,000 to 40,000 tons a year. A larger amount of low-alloy tool steels may be produced, raising the total tool steels output to perhaps 100,000 tons a year.

## III. ALLOY STEEL ECONOMY IN THE UNITED STATES AND GREAT BRITAIN

### Steel Production of the United States

As early as 1936, German steel production recovered from the depression of the early 1930's and continued to grow until the outbreak of the war. On the other hand, in 1939, the production of steel in the United States was about five percent under the 1929 level, having overcome a sharp drop in 1938, when there was a 44 percent decrease in steel production and a 45 percent cut in the output of alloy steel. Since the beginning of the war, a strong upward movement in steel production has taken place, as shown in Table 3.

TABLE 3

United States: Production of Steel and Alloy Steel, 1935-1943 (in 1,000 short tons)

| Years | Total steel | Alloy steel ingots a/ Total | Alloy steel ingots a/ Percent |
|---|---|---|---|
| 1935 | 38,200 | 2,100 | 5.5 |
| 1936 | 53,500 | 2,850 | 5.3 |
| 1937 | 56,650 | 3,000 | 5.3 |
| 1938 | 31,750 | 1,650 | 5.2 |
| 1939 | 52,800 | 3,210 | 6.1 |
| 1940 | 67,000 | 4,970 | 7.4 |
| 1941 | 82,850 | 8,200 | 9.9 |
| 1942 | 86,050 | 11,500 | 13.4 |
| 1943 | 91,000 | 14,500 | 15.9 |

Source: Minerals Yearbook 1939 and 1943 (Preprint), Bureau of Mines. For 1943, the figures of WPB.

a/ The figures for alloy steels include all steels containing over 0.4 percent of nickel, 0.3 percent of chromium, 1.65 percent of manganese, 0.5 percent of silicon, 0.1 percent of molybdenum, and any amount, no matter how small, of vanadium, tungsten, cobalt, titanium, and zirconium. They also include that insignificant portion of steel for castings produced in foundries operated by companies manufacturing steel ingots.

The alloy steel produced in the United States amounted to about five percent of the total steel before 1939 and rose to over 13 percent of the total in 1942. This upward trend continued in 1943, but the WPB estimates that in 1944 the proportion of alloy steel to total





steel output may be lower because the tonnage of carbon steel is expected to be higher than in 1943, with the output of alloy steel remaining the same.

### Wartime Requirements of Alloy Steel in the United States and the United Kingdom

The steel requirements of the United States and the United Kingdom are indicated in Table 4. It should be noted that information was available only for the third quarter of 1943 for the United States and the fourth quarter of 1943 for Great Britain. Also, the classification of steel uses by groups appears more exact in the table than is actually the case, and the same average ratio of conversion from finished steel product to ingots has been used for the products of each group. 3/ However, as only the ratio of alloy steel to total steel production, and not the absolute figures of United States or British steel requirements are essential for this report, the statistical shortcomings are of minor significance. Even so, attention must be called to the fact that the alloy steel ratio might have been somewhat different for a quarter of the year in which a larger program for aircraft or ammunition had been decided upon.

As Table 4 shows, alloy steel represented 16.6 percent of total United States steel requirements in the third quarter of 1943. This proportion must have been lower at other periods of the year, as the average for 1943 was under 16 percent. The proportion of alloy to total steel output in Great Britain is generally lower than in the United States, though in the case of aircraft, artillery, ammunition, motor vehicles, and agricultural machinery, it is higher.

3/ The tables prepared by the Combined Production and Resources Board of the United States, Great Britain, and Canada were for finished steel products. In converting the tonnage to ingot steel equivalents for Table 4, the following yield ratios were used:- for the United States--finished products, 70.4 percent of carbon steel and 62.2 percent of alloy steel; for the United Kingdom--finished products, 73.0 percent of carbon and 57.5 percent of alloy steel. The same average yield ratio was applied for all groups, although some, such as aircraft, have a much lower yield of finished products than, for instance, shipbuilding.

TABLE 4

United States and United Kingdom: Wartime Requirements of Carbon and Alloy Steel Ingots by Industrial Groups, 1943
(in 1,000 short tons)

| Group or Industry | United States, third quarter, 1943 | | | | United Kingdom, fourth quarter, 1943 | | | |
|---|---|---|---|---|---|---|---|---|
| | Carbon steel | Alloy steel | Total | % of alloy steel to total | Carbon steel | Alloy steel | Total | % of alloy steel to total |
| Aircraft | 507 | 643 | 1,150 | 55.9 | 82 | 145 | 227 | 63.9 |
| Armoured fighting vehicles | 460 | 915 | 1,375 | 66.5 | 116 | 147 | 263 | 55.8 |
| Artillery, small arms, etc. | 516 | 490 | 1,006 | 48.7 | 91 | 113 | 204 | 55.3 |
| Ammunition | 1,497 | 307 | 1,804 | 17.1 | 422 | 106 | 528 | 20.0 |
| Misc. field equip., air force and naval stores | 1,162 | 150 | 1,312 | 11.4 | 809 | 45 | 854 | 5.2 |
| Shipbuilding and engineering | 4,849 | 416 | 5,265 | 7.9 | 781 | 32 | 813 | 3.9 |
| Buildings and works | 1,483 | 61 | 1,544 | 3.9 | 258 | --- | 258 | 0 |
| Storage and transport of material | 1,587 | 43 | 1,630 | 2.6 | 132 | --- | 132 | 0 |
| Mining and quarrying | 259 | 37 | 296 | 12.5 | 183 | 2 | 185 | 1.1 |
| Chemical industries | 195 | 34 | 229 | 14.8 | 14 | 0.3 | 14 | 2.4 |
| Agricultural machinery | 321 | 21 | 342 | 6.1 | 41 | 3 | 44 | 7.1 |
| Machines, equip., tools for industry | 1,589 | 291 | 1,880 | 15.4 | 475 | 54 | 529 | 10.2 |
| Railways | 1,861 | 11 | 1,872 | .60 | 355 | 1 | 356 | 0.34 |
| Motor transport | 1,413 | 367 | 1,780 | 20.6 | 250 | 66 | 315 | 20.7 |
| Carbonization ind. and elec. supply | 384 | 47 | 431 | 10.8 | 29 | 1 | 31 | 3.9 |
| Export | 2,419 | 283 | 2,702 | 10.4 | 50 | 3 | 53 | 5.2 |
| Miscellaneous | 256 | 14 | 270 | 5.3 | 187 | 9 | 196 | 4.5 |
| Total | 20,758 | 4,130 | 24,888 | 16.6 | 4,275 | 727 | 5,002 | 14.5 |

Source: Combined Production and Resources Board, October 1, 1943.





## IV. THE GERMAN ALLOY STEEL ECONOMY

Long before the outbreak of hostilities, Germany had a highly developed system of alloy steel production, which it rapidly expanded for the impending emergency. Filling up the arsenals with war equipment, providing the army with tanks, trucks and ammunition, and supplying the Luftwaffe with airplanes created a growing demand for alloy steel, to be used in tools as well as in war materiel. No statistical information is available on the prewar output of alloy steel in Germany, but it is fairly certain that, because of war preparations, Germany was producing relatively more alloy steel than the United States where, up to 1939, about five percent of the total steel output consisted of alloy steel (see Table 3). The quantities of ferro-alloys imported, as well as the level of German war production and the tonnage and quality of tools and machinery exported, seem to indicate that about 10 percent of total German steel output was in alloy steels.

Table 4, showing the steel requirements of the United States and the United Kingdom, has been used in determining the ratio of alloy steel to total German steel output in 1943. Inasmuch as German steel production differs in some respects from that of the United States and Great Britain, a variety of factors, such as the German tooling system and the traditional composition of some of its alloy steel, had to be evaluated. Steel allocations for each group were decided on the basis of the importance of the group, how much alloy steel it would need, and which of the final products might be sacrificed by Germany with the progressive loss of some ferro-alloy supplies. Table 5 presents estimates of the 1943 German steel allocations for the 17 groups or industries for which United States and United Kingdom requirements have been shown.

In view of the damage inflicted on Enemy Europe's steel production through bombing, there is general agreement among the Ministry of Economic Warfare, the Foreign Economic Administration, and the Office of Strategic Services on the figure 35 million tons as Enemy Europe's total steel production in 1943.

The estimate of the decrease from the 1942 level seems justified because of changes in the war situation in 1943. It is logical to assume, for example, that Germany reduced the output of rails in 1943 and used less structural steel for buildings in 1943 than in 1942. On the other hand, in 1943, Germany had to increase the number of fighter planes as a defense against increasing air attacks, with a resulting rise in steel allocations for aircraft.

TABLE 5

Enemy Europe: Alloy and Total Steel Allocations by Industrial Groups in 1942 and 1943

| Group or Industry | Total steel (1,000 metric tons) MEW 1942 | Total steel (1,000 metric tons) 1943 | Percent of alloy steel to total steel a/ 1943 | Alloy steel (1,000 metric tons) a/ 1943 |
|---|---|---|---|---|
| Aircraft | 600 | 700 | 64 | 450 |
| Armoured fighting vehicles | 1,300 | 1,225 | 65 | 800 |
| Artillery, small arms, etc. | 850 | 900 | 55 | 475 |
| Ammunition | 7,000 | 7,000 | 22 | 1,540 |
| Misc. field equipment, Air Force and Naval stores | 2,900 | 3,000 | 5 | 150 |
| Shipbuilding and engineering | 2,100 | 1,650 | 6 | 100 |
| Buildings and works | 4,500 | 3,800 | -- | --- |
| Storage and transport of materials | 2,000 | 1,500 | -- | --- |
| Mining and quarrying | 1,100 | 850 | -- | --- |
| Chemical industries | 450 | 700 | 15 | 105 |
| Agricultural machinery | 2,050 | 1,425 | 5 | 70 |
| Machines, tools for various industries | 1,750 | 1,750 | 10 | 175 |
| Railways | 9,100 | 7,800 | -- | --- |
| Motor transport | 1,200 | 800 | 20 | 160 |
| Carbur. and electric supply | 1,150 | 1,000 | 8 | 80 |
| Exports | 250 | --- | -- | --- |
| Miscellaneous | 1,400 | 1,150 | 3 | 35 |
| Total | 39,700 | 35,250 | 11.8 | 4,140 |

Source: MEW, German Europe's Iron and Steel Supply Position in 1942, September 20, 1942;
Estimates (two last columns) are based on the United States and British patterns of production.

a/ The dash indicates that the amount of alloy steel used in a specific group of products is inconsequential.





To establish the ratio between alloy and carbon steel in Germany for each group of steel products, the United States and British patterns were used alternately. For some groups, however, the pattern of neither country was found applicable, because it was believed to differ from German practice. While 12.5 percent of the steel employed in mining and quarrying in the United States is alloy steel (1.1 percent in Great Britain), it is estimated that no alloy steel, or an insignificant amount, was used for these purposes in Germany in 1943. This is also true of exported steel goods. On the other hand, in spite of the fact that United States aircraft requirements of alloy steel amounted to 56 percent of total steel used in aircraft, the ratio in Germany was estimated at 64 percent, as in the British aircraft, because higher stress levels and designs calling for more alloy steel are used in German aircraft. Moreover, as the United States figure for steel used in the aircraft group includes all packing material--even to the carbon steel plates for shipping engines from one plant to another--and the German figure includes no packing material, a higher proportion of alloy steel to total steel is to be expected for Germany than for the United States.

The United States percentage of alloy steel was accepted for the armored fighting vehicles group in Germany, and the British percentage for artillery. A higher percentage of alloy steel for ammunition than is required either in the United States or in Great Britain was adopted for Germany because the Germans use more A.P. shell which is made entirely of alloy steel.

The 1943 German allocations of alloy steel for all groups were estimated at approximately 4,140,000 tons, or 11.8 percent of total steel allocated. On the basis of an earlier estimate (see Different Types of Alloy Steel) that of all alloy steel produced in Germany, about 92 percent is engineering steels, 5 to 5.5 percent stainless steels, and the balance tool steels, the tonnage may be distributed as follows:

| | |
|---|---|
| Engineering steels | 3,810,000 metric tons |
| Stainless steels | 230,000 " " |
| Tool steels | 100,000 " " |
| Total | 4,140,000 metric tons |

## V. ENEMY EUROPE'S REQUIREMENTS OF FERRO-ALLOYS

### Engineering Steels

Engineering steels consume the bulk of ferro-alloy supplies. However, a greater range of interchangeability is possible in engineering than in stainless or tool steels.

In the United States, the making of 1,000 tons of engineering steels consumes on the average 11.0 tons of manganese, 5.8 tons of chromium, 1.3 tons of molybdenum and four tons of nickel (see Table 2). With the output of engineering steels in Germany in 1943 at an estimated 3.8 million tons, the approximate quantities of ferro-alloys consumed, assuming that the United States pattern was followed and that these alloying elements or their equivalents were available, would be as follows:

42,000 metric tons of contained manganese,
4,950 metric tons of contained molybdenum,
22,100 metric tons of contained chromium, and
15,250 metric tons of contained nickel.

As will be shown in the section, Supplies of Ferro-Alloys in Enemy Europe, such quantities, particularly of nickel and molybdenum, are far beyond German command, so that the German pattern must have been considerably modified.

### Stainless Steels

The major alloys used in the production of stainless steels are chromium and nickel. The customary metallurgical practice in the production of stainless steels in the United States is to use at least five percent nickel and 10 percent chromium on an ingot-new alloying element basis.

In some instances, the percentage of nickel consumption is much higher--eight percent or even more in the installations of rubber, explosive, or powder plants, or in the equipment for making organic chlorides. However, of the nickel charged to the furnace, about 55 percent is shipped out, the rest serving as a "revolving fund" for further production. Thus, the overall consumption of virgin nickel in stainless steels in the United States is estimated at five percent.

Up to 17 and 18 percent of chromium, with small variations from month to month, is used in the United States.

In view of Germany's economical use of ferro-alloys, the estimate of German consumption of chromium in making stainless steels is set at the almost irreducible minimum of 10 percent, and the nickel consumption at two percent. In fact, Germany has





developed one stainless steel on a nickel-free basis with 12 percent manganese and 8 to 9 percent chromium. However, as there are indispensable and comparatively high requirements for nickel in some stainless steels, Germany cannot do entirely without it. The estimate of an overall nickel consumption of two percent in stainless steels appears reasonable.

As the estimate of the German total output of stainless steels in 1943 was about 230,000 metric tons, the ferro-alloy requirements for these steels may be set at about 23,000 metric tons of chromium and 4,600 tons of nickel, plus some manganese.

### Tool Steels

Germany has probably had to do extensive retooling, both in domestic plants, because of wear and damage through bombing, and in plants of occupied countries working on German account. Furthermore, the percentage of steel output that requires machining operations is greater in Germany than in the United States because in the United States a large part of the total steel output is used in the shipbuilding industry in which fewer machining operations are necessary.

On the other hand, the latest examination of the German machine gun 42 (1942 Model), the successor to the standard German machine gun 34, showed that 98 percent of the gun is made of stampings, with a bare minimum of machining. Evidently the Germans redesigned the model in order to reduce to a minimum the number of machine tool hours and lighten the burden placed on their tooling system.

It was estimated (see Tool Steels under Different Types of Alloy Steels) that German requirements for tool steels, including carbide tools, were in about the same proportion to alloy steel as in the United States, i.e., about 2.5 to 3 percent in 1943.

Although output of tool steels is relatively small, tool steels absorb a substantial share of certain ferro-alloys. They consume large amounts of vanadium and of tungsten, even in the United States where molybdenum is frequently used instead of tungsten. In addition, tool steels call for a proportionately larger quantity of chromium and molybdenum than does alloy steel in general.

As shown in Table 6, tool steels, amounting in 1944 to less than two percent of total alloy steel tonnage in the United States, claim about half of the vanadium and two-thirds of the tungsten consumed

in the steel industry. The War Production Board anticipates an even higher consumption of these two metals, provided the restrictions now in force on the relative composition of high-speed tool steels are relaxed.

TABLE 6

United States: Ferro-Alloys Consumed in Tool Steels (contained metal)

| | Actual consumption in the first eight months of 1943 | | Estimated consumption in 1944 | |
|---|---|---|---|---|
| Ferro-Alloys a/ | Total (short tons) | Percent of total consumption of each alloy. | Total (short tons) | Percent of total consumption of each alloy. |
| Chromium | 2,385 | 2.7 | 3,500 | 2.3 |
| Molybdenum | 1,020 | 8.9 | 1,730 | 7.8 |
| Vanadium | 485 | 50.7 | 885 | 46.9 |
| Tungsten | 3,350 | 70.0 | 6,340 | 64.6 |

Sources: WPB, Ferro-Alloys Branch, report, Status of Ferro-Alloys, October 27, 1943; WPB, Bureau of Planning and Statistics, report, Expected Consumption of Ferro-Alloys, September 17, 1943.

a/ The amount of nickel consumed in tool steels is too small to warrant its inclusion.

It should be borne in mind that the German tooling system is much more dependent on tungsten carbide tools than the United States system. These tools can be made of carbon steel upon which are brazed tips of high tungsten content, which permit operation of the tools at very high speed and at very high temperatures. The carbide tips, although brittle and requiring very stable, rigid, shock-resistant machinery, save manpower and time in the production of war equipment when properly applied. Because of their special qualities, carbide tools were widely installed in German plants before the war. About 20 percent of the tools in Germany are estimated to be of the carbide type; the rest are of high-speed steel containing an irreducible average of four percent tungsten.

Even before 1939, Germany gave up the standard composition of high-speed steels, the so-called 18-4-1 type: 18 percent tungsten, four percent chromium and one percent vanadium. According to





MEW, the tungsten content of German tool steels was 14 percent in 1940, 10 percent in 1941, and has been between 2.5 and five percent ever since. On the other hand, German sources indicate that Germany shifted to an even lower percentage of tungsten in tool steels at a much earlier date (see Table 7).

TABLE 7

Enemy Europe: Percentage of Alloy Content in High-Speed Tool Steels

| Period | C | Cr | W | Mo | V |
|---|---|---|---|---|---|
| | (0.75 | 4.2 | 18.0 | - | 1.0 |
| 1924 to 1926 | (0.80 | 4.2 | 25.0 | 0.8 | 1.5 |
| | (0.85 | 4.2 | 14.0 | - | 2.2 |
| | (0.75 | 4.2 | 11 | 0.5 | 0.9 |
| | (0.80 | 4.2 | 11 | 0.7 | 1.4 |
| 1936 on | (0.85 | 4.2 | 12 | 0.7 | 2.5 |
| | (1.0 | 4.2 | - | 3.4 | 2.8 |
| | (1.0 | 4.2 | 2.1 | 3.1 | 2.1 |
| | (0.7 | 4.2 | 2.0 | 8.0 | 1.0 |

Source: From the paper "Trends in the Development of Alloy Steels", read by Ed. Houdremont before the Annual Meeting of the Verein Deutscher Eisenhüttenleute, published originally in Technische Mitteilungen Krupp, May 1939, and reproduced in Metallurgia, July 1939, pp. 121 to 123. The author adds that after 1935 the use of "foreign alloys had to be limited in Germany as far as possible."

As can be seen in Table 7, the Germans compensated for the lower percentage of tungsten by using more of either vanadium or molybdenum.

Taking these factors into consideration, and allowing for possibly substantial reserves of tungsten tools and the recovery of tungsten from worn out or broken tools, it is estimated that about 3,000 metric tons of tungsten concentrates, or 1,500 metric tons of contained metal, were used in Germany in 1943 for the production of tools. A fourth of this may have gone into tool steels, the balance into tungsten carbide. This amount of tungsten is considered an irreducible minimum.

Vanadium is probably applied in Germany on a larger scale than in the United States, because it is produced domestically, and it has to substitute for tungsten which, though available, can be obtained from the Iberian Peninsula only at exorbitant prices and from Japan, at the risk of running the blockade. It is estimated that 885 short tons of vanadium will be required to produce 70,000 tons of high-speed steels in the United States in 1944 (see Table 6). All factors considered, it is reasonable to assume that about 500 metric tons will be required for the production of 40,000 tons of high-speed tool steels in Germany.

Requirements for molybdenum can be estimated at approximately 1,000 tons of contained metal. As such a quantity is not likely to be at Germany's disposal, it is assumed that tungsten, or, more probably, vanadium, is substituted.

The amount of chromium used in tool steels is relatively small, perhaps 1,500 tons.

An additional alloying element used in the manufacture of tungsten carbide, and therefore in the production of tools, is cobalt, which bonds the tungsten powder to a stable mass after it has been pressed to the desired shape. About 6 to 8 percent of the tungsten carbide consists of cobalt. If 1,000 to 1,100 tons of tungsten metal are reserved for the production of carbide, approximately 60 to 80 tons of cobalt will be needed.

## Additional Requirements of Ferro-Alloys in Germany

Apart from the amounts of the ferro-alloys consumed for the alloy reaction in the production of engineering, stainless, and tool steels, Germany requires additional amounts of some of them, particularly manganese, for other indispensable uses.

Of the eight main alloy metals considered in this report, manganese occupies a unique position, being indispensable to the production of steel, regardless of the type. This vital alloy neutralizes sulphur and improves the rolling quality, or malleability of the steel. In the United States, 13 to 14 pounds of manganese per short ton of total steel produced are regarded as the standard average, with the following distribution: about 11 pounds per ton in carbon steel, 24 pounds per ton in castings, 19 pounds per ton in alloy steel, and 33 to 34 pounds per ton in basic manganese type alloy steel.





Germany may be exercising a much more stringent economy than the United States in the use of manganese, but it cannot go below about 12 pounds per metric tons of carbon steel, because further reduction would affect the quality of the steel. It seems certain that the Germans would reduce the manganese content in alloy steel before lowering the quality of carbon steel. Allowing 12 pounds of manganese per metric ton of steel, about 190,000 metric tons of contained manganese would be required for the annual production of about 35 million tons of steel.

However, it is known that Germany cut its manganese requirements to some extent at the blast furnaces by adding a certain amount of soda ash to the liquid iron to extract the sulphur. Soda ash combines with sulphur and rises to the surface in a form of slag which is then removed. As soda ash can be readily produced in Germany, within the limits of manpower and transportation, it can be assumed that such desulphurization of iron has been widely practiced. Not all blast furnaces, however, can operate with soda ash. It was reported that about 20 percent of all pig iron has been desulphurized by the soda ash treatment in Germany, with a saving in manganese on approximately 12 million tons of steel of about 15 percent. As a result, the consumption of manganese may have been lowered by about 10,000 tons. Thus, in 1943, Germany may have consumed as much as 180,000 tons of contained manganese for deoxidizing and improving the malleability of its steel.

Another essential use made of manganese is in manganese dioxide for dry cells. High-grade manganese dioxide (98 percent) is needed for this purpose. Perhaps 5,000 to 6,000 tons of manganese per year are consumed in this way by Germany.

Tungsten is considered indispensable in the manufacture of filaments for electric bulbs. No practicable substitute is available to Germany. Tungsten is preferred for this purpose because it can be drawn into extremely fine wire and has the highest melting point of any metal. Thin tungsten wire, 0.0004 inch in diameter, is also used for cross-hairs in telescopes, and filaments in radio and X-ray tubes. Tungsten contact points are employed in spark coils, voltage regulators, telegraph keys, and similar devices.

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Tungsten is also indispensable in catalysis.

The latest estimate of German tungsten consumption for filaments and radio tubes is around 300 tons a year; for catalytic

purposes, about 200 tons.

The third alloying element having important additional uses is cobalt. Cobalt steel magnets are particularly efficient and at the same time more adaptable because of their smaller size. Cobalt is also important as a catalyst in Fischer-Tropsch plants producing synthetic oil. Opinion is divided as to whether the Germans are giving priority to the metallurgical use of cobalt in tungsten carbide and magnet steels, or to its chemical use for purposes of catalysis. There are reports that new catalysts installed in Germany are made of iron and that cobalt is used exclusively for regeneration of the old catalysts.

It is estimated that in addition to the cobalt used in the production of tungsten carbide, Germany allocated about 180 tons of cobalt in 1943: 80 tons for catalysis, and the balance for magnet steels. Since the catalysis in Fischer-Tropsch plants requires the consumption of cobalt and nickel at the ratio of 1 to 2, about 160 tons of nickel are also needed for this purpose.

### Estimate of German Ferro-Alloy Allocations in 1943

Germany's 1943 allocations of each ferro-alloy important in making alloy steel are summarized in Table 8. It should be stressed again that these allocations for engineering steels are calculated on the basis of the war pattern of United States and British steels and not on the basis of German supplies of ferro-alloys, which will be discussed in the next section.





TABLE 8

Enemy Europe: Calculated Ferro-Alloy Allocations in 1943
(contained metal, in metric tons)

| Ferro-alloy | Use | Approximate quantity |
|---|---|---|
| Manganese a/ | carbon steel | 180,000 |
| | engineering steels | 42,000 |
| Chromium a/ | stainless steels | 23,000 |
| | engineering steels | 22,100 |
| | tool steels | 1,500 |
| Nickel b/ | stainless steels | 4,600 |
| | engineering steels | 15,250 |
| | catalysation | 160 |
| Molybdenum | tool steels | 1,000 |
| | engineering steels | 4,950 |
| Tungsten c/ (concentrates) | tool steels, carbide filaments, electrodes, catalysts | 3,500 |
| Vanadium d/ | tool steels | 600 to 650 |
| Cobalt | tungsten carbide | 60 to 70 |
| | magnet steels | 100 |
| | Fischer-Tropsch plants | 80 |

Source: Based on United States steel-making pattern.

a/ In addition, some manganese is needed for stainless steels and some chromium for high-speed steels. It is assumed that because of short supplies Germany is using no chromium for chrome plate and refractories.

b/ A small tonnage of nickel also goes into the manufacture of airplane detecting equipment.

c/ Tungsten is also consumed in Germany in the manufacture of carbide cores for armor-piercing projectiles. The quantities allocated for this purpose cannot be ascertained but, in the opinion of both United States and British experts, they amount to the residual of German supplies after the indispensable industrial uses have been satisfied. Therefore, this use of tungsten has not been included in this study.

d/ Including some supplies used to substitute for molybdenum.

## VI. SUPPLIES OF FERRO-ALLOYS IN ENEMY EUROPE IN 1943

The German policy of exploiting to the full the economic resources of occupied Europe has been particularly important in the case of ferro-alloys.

Possessing no alloying elements within its own borders, except vanadium (and even this is obtained chiefly from the iron ore of France, Belgium, and Luxembourg), Germany in 1943 depended on supplies of manganese from Occupied USSR, molybdenum from Norway, nickel from Finland, and chrome from the Balkans. In addition, the few countries remaining neutral have been unable to resist entirely the pressure of German demands for ferro-alloys. Important supplies of chrome have been obtained from Turkey and tungsten from Spain and Portugal.

Even with these resources at its command, Germany has had to make existing supplies of ferro-alloys go as far as possible. Two factors have contributed to their most efficient utilization in war material: 1) the introduction of the so-called "substitute steels," and 2) the total mobilization of scrap throughout the entire area under German control.

### Substitute Steels in Germany

The United States and Great Britain responded to the shortage of certain ferro-alloys by introducing National Emergency Steels and War Emergency Engineering Steels, respectively. Germany introduced substitute steels (Austaush-Stähle). The aim was the same: to economize in the use of those ferro-alloys of limited supply by shifting to others more readily available.

In order to close all avenues of waste, meticulous studies were made of steel compositions used, extensive tests were conducted, and interested industries were consulted. As a result, a relatively small number of the most appropriate steel types were selected, and the steel-makers were ordered not to demand for their products any physical properties in excess of the absolute minimum essential to safety.

As has been noted, in general the war emergency steels, although containing less alloy metals than the prewar steels, are not inferior in quality or effectiveness. While leaner in alloy composition and offering a lower safety insurance, they





are adequate for the purposes for which they are made. This holds true for Germany as well as for the United States.

Recently, Germany tightened the regulations on substitute steels. On June 10, 1943, the German Metal and Iron Board issued a ruling containing lists of materials to be used in each industry. These lists constitute actual specifications for the manufacture of various products; arbitrary changes in the specifications are forbidden. About 30 lists have been made public so far, and new lists continue to appear. They are compulsory not only for Germany but also for the occupied countries so that ferro-alloy practices throughout Enemy Europe have been standardized.

### Scrap Mobilization in Enemy Europe

The importance of scrap in steel-making has already been described (see Use of Scrap in Making Alloy Steel). Without the ferro-alloy supplies provided by scrap, it would have been impossible to manufacture ammunition or other military steel products of the quality achieved by the belligerents on both sides.

However, it should be stressed that Germany is making more exhaustive use of scrap and is segregating it in a more systematic way than is either the United States or Great Britain. Total scrap mobilization has been effected in Germany, and every item that was not absolutely necessary for the functioning of a minimum civilian economy was withdrawn from private households and even factories. Scrap collecting units for each block or street in every city have been responsible for a complete combing for every possible scrap item. The railways have set up a special department for salvage of waste material which is usually considered not worth collecting because of labor cost. Prisoners were put at the disposal of the railways for this purpose, and the results have been declared very satisfactory.

The concept of "scrap" was broadened when the Germans initiated looting campaigns in the conquered countries. Requisitioning and compulsory collections have been systematically carried out in all of the occupied territories. In addition, the Germans introduced battlefield collections. Each division of the German Army has one or more companies for salvaging scrap, particularly alloy steel parts. The officers of these companies are trained to recognize parts containing important alloys which are shipped in separate boxes directly to specific mills. Aside from the regular salvage troops, the Army in general has been made scrap conscious, and each platoon has two or more men able to assist technically in salvage operations and scrap segregation. While it is true that little or no salvaging can be expected during retreat, stationary operations permit the salvaging of a high percentage of scrap.

The Germans began to economize on ferro-alloys long before the war--much earlier than did the United States--, and they have made substantial recoveries of scrap both at home and in occupied territories. However, as they have been producing lean-alloy steel for years, the quality of domestic scrap available has continually declined. Thus their need for virgin alloys is more urgent than is that of the United States, although the Germans claim that, as a result of their efforts in scrap salvage as well as their economy in the utilization of virgin ferro-alloys, they have been able, up to the present, to satisfy the pyramiding demands of the steel industry for ferro-alloys.

## Individual Ferro-Alloys

Manganese. Thanks to the rich manganese mines of Nikopol, German supplies of manganese, the indispensable ferro-alloy, were relatively ample in 1943. Before their withdrawal from Nikopol, the Russians reportedly destroyed the ground installations and flooded the pits of the mines. The stocks of ore which fell into German hands and were shipped to Germany in 1942 were not very large, about 165,000 tons, or 60,000 to 65,000 tons of contained manganese. The work of rehabilitating the mines started at once. According to an official Russian source, new pits were opened in November and December 1942, and the output of ore in the first eight months of 1943 amounted to 500,000 tons, or 180,000 tons of contained manganese. In view of the importance of this metal to the German steel industry, the Germans probably spared no efforts to obtain as much manganese as possible from the Nikopol mines in the last four months of 1943. However, because of the difficulties arising from the proximity of the battlefront, it is assumed that the Germans produced and shipped out of Nikopol in that period only about as much manganese as they did in any other two months of the year, making a total of about 625,000 tons of ore (225,000 tons of contained manganese) obtained during the entire year of 1943.

With the exception of Nikopol, there are under German control no manganese deposits which produce a high-grade ore, although many small mines supply Germany with quantities of low-grade ore. Such mines are found in Germany proper, in the Balkans, in Hungary, in Czechoslovakia, and in Italy. The Czechoslovakian annual output amounts to approximately 100,000 tons of 17 percent manganese or about 14,000 to 15,000 tons of recoverable manganese. Even before the war, Hungarian production was in German hands, the Deutsche Bank holding the largest interest in the chief manganese deposit near Urkut. At the present time the Hungarian output may be close to 10,000 or 12,000





tons of contained manganese. Altogether, the mines in Enemy Europe, outside of Germany proper, and excluding Nikopol, may have produced about 75,000 tons of manganese metal in 1943.

Also important to Germany as a source of manganese is the deposit of manganiferous iron carbonate ore in the district of Siegerland. Crude ore from this deposit contains 4 to 5 percent manganese, but roasting raises the manganese content to about nine percent. The roasting process is, however, a costly one and involves large equipment. Germany is producing ferro-manganese from this ore by first smelting the ore into spiegeleisen. Later, part of the spiegel is treated in a basic converter, and part in an acid converter. The two slags are mixed for a blast furnace charge, the silica content of one being neutralized by the lime content of the other. The Germans claimed before the war that the ferro-manganese produced was of good quality.

According to some reports, the annual production of manganese from this source can theoretically be stepped up to the almost incredible figure of 550,000 tons of high-grade manganese ore, or approximately 190,000 tons of contained manganese. However, competent metallurgists in the United States are inclined to discount the possibility that any important amount of manganese can be obtained from this source.

TABLE 9

Enemy Europe: Supplies of Manganese January 1, 1942
to January 1, 1944
(contained metal in metric tons)

| | | |
|---|---|---|
| Stocks on January 1, 1942 | | 75,000 |
| Current supplies in 1942: | | |
| from Occupied U.S.S.R. | | |
| (Stocks of Nikopol) | 65,000 | |
| Germany | 50,000 | |
| Czechoslovakia, Italy, Hungary, Bulgaria, Roumania, Yugoslavia and Greece | 75,000 | 190,000 |
| Total supplies | | 265,000 |
| Consumption: | | |
| Deoxidation of 40 million tons of steel (5.5 kg. per ton) | 210,000 b/ | |
| Engineering steels a/ | 50,000 | |
| Dry cells | 5,000 | 265,000 |
| Total consumption | | 265,000 |
| Stocks on January 1, 1943 | | c/ |
| Current supplies in 1943: | | |
| from Occupied Russia | 225,000 | |
| Germany | 50,000 | |
| Other European countries as above | 75,000 | 350,000 |
| Total supplies | | 350,000 |
| Consumption: | | |
| Deoxidation of 35 million tons of steels | 180,000 b/ | |
| Engineering steels a/ | 77,000 | |
| Dry cells | 5,000 | 262,000 |
| Total consumption | | 262,000 |
| Stocks on January 1, 1944 | | 88,000 |

Source: Confidential sources.

a/ The consumption of manganese in engineering steels is explained in the section German Alloy-Steel Economy, and in German Pattern of Alloy Power in 1943 and 1944.
b/ Approximate figure.
c/ No information is available on any stocks outside of the current pipe-line reserves.





Chromium. Most of Germany's supplies of chrome ore are obtained either from the Balkan areas or from Turkey. The Allatini Mines of Yugoslavia, with an annual output of about 16,000 tons (metal content) are the most important source. Of the chrome ore supplied to Germany in 1943, about two-thirds came from Yugoslavia, Greece, and Albania, and one-third from Turkey. The so-called second Clodius Trade Agreement between Germany and Turkey provided for Turkish delivery to Germany of 90,000 tons of chrome ore in 1943, contingent on German delivery to Turkey of compensative commodities. About 40,000 to 42,000 tons of chrome ore (48 percent metal content) were shipped from Turkey to Germany in 1943. In view of the fact that some ships may have been sunk, it is believed that the amount of contained chromium obtained by Germany from this source could not have been more than 12,000 tons. Including stocks on hand at the beginning of the year and small amounts from Bulgaria and Roumania, the total quantity of chromium available to Germany in 1943 is estimated at about 49,000 tons (see Table 10).

TABLE 10

Enemy Europe: Supplies of Chrome, 1943
(contained metal in metric tons)

| | |
|---|---|
| Stocks on January 1, 1943 | 4,000 |
| From Turkey | 12,000 |
| Yugoslavia | 19,000 |
| Greece | 7,000 |
| Albania | 5,000 |
| Bulgaria and Roumania | 2,000 |
| | 49,000 a/ |

Source: Confidential sources.

a/ It is reported that perhaps 2,000 tons of chrome ore were received from Portugal in 1943.

Nickel and molybdenum. Both nickel and molybdenum were in very short supply in Enemy Europe in 1943. New supplies of nickel amounted to about 7,000 tons, half of which came from the mines of Petsamo, Finland, where nickel is also refined in a newly constructed smelter. Finnish output has been increasing since the completion of the smelter installations in the summer of 1943. Germany proper, Greece, and Norway produce about the same quantity, roughly 1,000 tons a year each. Germany may have some small reserves of nickel; the amount has not been ascertained.

Molybdenum is produced chiefly in Norway, the Knaben mines accounting for about 90 percent of the total Norwegian output. Their normal production ranged between 250 and 400 tons of metal a year. In March 1943, the Knaben mines were heavily bombed, and the production almost stopped for two months. In June and July the output was only about 10 to 12 tons a month. It may be assumed that in the second half of 1943, production again reached almost normal level, so that German molybdenum supplies from Norway may have amounted to 300 tons in 1943.

Late in that year, the mines were again subjected to intensive bombing, and the crushing, grinding and classifying plant was badly damaged. Restoration was delayed, because Germany was unable to secure from Sweden all the necessary machinery.

Finland's new and only mine, Maetegvara, turned out about 30 tons of molybdenum in 1942. A 1943 program called for the production of about 200 tons. Roumania supplied about 100 tons of molybdenum in 1943.

Making some allowance for the production in the Balkans and assuming reserves from 1942 of about 200 tons, it is estimated that total supplies of molybdenum in Enemy Europe in 1943 may have reached 850 to 900 tons.

Tungsten, vanadium, and cobalt. Of the three alloying metals used mainly in the production of high-speed and tool steels, tungsten and vanadium were probably available in quantities sufficient to meet essential 1943 allocations, while the cobalt position was very tight. Tungsten is produced almost exclusively in the Iberian Peninsula, and the exports to Germany in 1943 amounted to 1,300 tons from Spain and 1,800 tons from Portugal. It has also been reported, but not verified, that Germany moved from Spain 500 to 600 tons of stored tungsten. Germany derives small additional supplies of tungsten, perhaps 200 tons a year, from domestic production. Whether Germany is obtaining further supplies from the Far East via blockade running is questionable. One indication of such a possibility is the fact that crews captured from ships and submarines sunk on this route testified that tungsten was a part of the cargo, though in small quantities, and that it always rated the highest priority. However, since no direct information is available on this point, supplies from this source have not been considered in the estimates of German supplies.

No vanadium ores are commercially mined within Enemy Europe or, for that matter, on the European Continent, but Germany has developed a method of obtaining vanadium from minette iron ore as well as from





vanadium-bearing ores in its own territory. This method, introduced in its final form by von Seth, calls for an extra reblowing of molten pig iron in the acid Bessemer converter, which results in the isolation of slag with rich vanadium content. After this, a complicated chemical treatment completes the extraction of vanadium. From every 1,000,000 tons of minette ore treated this way, about 250 tons of vanadium can be produced. In other words, to obtain one ton of vanadium, over 4,000 tons of iron ore must be subjected to special treatment. As this process of vanadium separation introduces an additional step in steel-making, it necessarily slows down the output of steel. 4/ Although the steel plants of Enemy Europe have excess capacity, there are manpower and transportation limitations. It is, therefore, assumed that only about five percent of total steel production within the German-controlled area is subjected to the onerous process of vanadium extraction. Current annual supplies of vanadium, therefore, are probably no more than about 1,000 tons.

Cobalt supplies are extremely short, amounting to perhaps 250 or 300 tons in 1943. About half of this amount comes from Germany proper, the balance from Finland.

Supplies of alloying metals available in Enemy Europe in 1943 are summarized in Table 11.

4/ A detailed description of vanadium production in German Europe is given in the FEA report, EP-37-YY, Vanadium, October 22, 1943.

TABLE 11

Enemy Europe: Supplies of Ferro-Alloys, 1943
(contained metal in metric tons)

| Alloying element | Stocks at the beginning of the year | Supplies obtained during 1943 | Total |
|---|---|---|---|
| Manganese a/ | b/ | 165,000 c/ | 165,000 |
| Chromium | 4,000 | 45,000 | 49,000 |
| Nickel | b/ | 7,000 | 7,000 |
| Molybdenum | 200 | 650 to 700 | 850 to 900 |
| Tungsten (concentrates) | 500 | 3,300 | 3,800 |
| Vanadium | 200 | 1,000 | 1,200 |
| Cobalt | - | 250 to 300 | 250 to 300 |

Source: Estimates based on confidential sources.

a/ Only that additional tonnage of manganese which is used as a ferro-alloy is included in this table. The tonnage (180,000 tons) annually consumed, and indispensable, in the making of carbon steel, is excluded under Supplies Obtained During 1943.
b/ No information is available concerning stocks outside the current pipe-line reserve.
c/ Does not include 5,000 tons of manganese used in dry cells.
d/ In addition, the 500 to 600 tons of tungsten which were stored in Spain may now be in the possession of Germany.

German Pattern of Alloy Power in 1943 and 1944

A comparison of German ferro-alloy requirements for 1943 (Table 8) with supplies available for that year (Table 11) leads to the conclusion that Enemy Europe 1) had reserves of manganese in excess of requirements; 2) has been able to meet essential requirements of chromium, tungsten, and vanadium; and 3) is very short in nickel, molybdenum, and cobalt. A comparison indicates also that, while production of stainless and tool steels of the required quality was possible with the ferro-alloys at Germany's disposal, the requirements for engineering steels, and thus for Germany's ordnance, could have been satisfied in 1943 with the virgin metals on hand only if the pattern of alloy power similar to that used in United States wartime steel production had been abandoned and a new pattern, adapted to the realities of the German ferro-alloy supply situation, put into effect.





Table 2 showed that the United States pattern of engineering steels required 41.6 units of alloy power for every 1,000 tons of steels produced. This minimum of alloy power must also be present in German engineering steels. If some particular alloying elements are not available, the 41.6 units must come from another combination of elements. According to Table 11, Enemy Europe in 1943 actually had available for use as virgin metal in engineering steels only two ferro-alloys: manganese and chromium. The small tonnage of available nickel and molybdenum was undoubtedly needed for stainless and tool steels. The use of chromium may have had to be reduced below the level of the United States pattern. Manganese, however, could have been used in much larger quantities.

It is estimated that of the 41.6 units of alloy power needed for 1,000 tons of steels, 18.4 units could have been obtained from chromium, but that the remaining 23.2 units must have come from manganese. The difference between this pattern and that of the United States may be represented as follows:

Alloy power per 1,000 tons of engineering steels

| United States' pattern | German pattern |
|---|---|
| 13.8 units from manganese | 23.2 units from manganese |
| 5.4 units from molybdenum | -- |
| 18.4 units from chromium | 18.4 units from chromium |
| 4.0 units from nickel | -- |
| 41.6 units of alloy power from virgin metal. | 41.6 units of alloy power from virgin metal. |

If this is the pattern used in Germany, the 41.6 units of alloy power must be derived from:

18.6 tons of contained manganese and
5.8 tons of contained chromium per each
1,000 tons of engineering steels.

Thus, by force of circumstances, Germany may have shifted in 1943, or is about to shift, from a four-alloy pattern of alloy power--the pattern used in United States engineering steels--to a far less balanced two-alloy pattern. Having no access to important supplies of nickel and molybdenum, as does the United States, Germany may have been compelled to adopt a pattern of alloy power using manganese and chromium exclusively insofar as virgin metals are concerned.

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Under such circumstances, the demands upon manganese supplies for the making of engineering steels must be very heavy. As 18.6 tons of manganese would be required for each 1,000 tons of engineering steels, about 77,000 tons were probably needed for the total tonnage of German engineering steels in 1943.

The following table summarizes the estimates of both supplies and requirements of four ferro-alloys in Enemy Europe in 1943, as analyzed above. In the first column are shown only those supplies which were left available for the engineering steels after the minimum demand for stainless or tool steels had been satisfied.

TABLE 12

Enemy Europe: Major Ferro-Alloys in Engineering Steels, 1943
(contained metal in metric tons)

| Alloying element | Supplies available for engineering steels | Requirements for four-alloy system | Surplus (+) or deficit (-) | Requirements for two-alloy system | Surplus (+) or deficit (-) |
|---|---|---|---|---|---|
| Manganese | 165,000 | 42,000 | + 123,000 | 77,000 | + 88,000 |
| Chrome | 30,000 | 22,100 | + 7,900 | 22,100 | + 7,900 |
| Nickel | 2,250 | 15,250 | - 13,200 | --- | --- |
| Molybdenum | - | 4,950 | - 4,950 | --- | --- |

Source: Estimates based on confidential sources.

Table 12 indicates that Germany would have been forced to resort to a two-alloy system in 1943 if it had had to depend exclusively on new alloy metals to be added to steel. However, the utilization of scrap permitted the enrichment of engineering steels with small quantities of ferro-alloys which otherwise would have been lacking. Germany can obtain from scrap insignificant amounts of molybdenum, somewhat more of nickel, and also some chrome. Furthermore, as Table 12 shows, Germany had about 2,000 tons of nickel to be used in engineering steels. This amount is too insignificant to be considered with respect to the total output of engineering steels, but engineering steels for certain high-priority uses can be, and probably are, provided with sufficient nickel to influence the quality. (This may be the case in the face-hardened armor plate of the Mark VI tank.) Finally, Germany can apply vanadium to some extent in order to improve the quality of the engineering steels.





The most important of these minor ferro-alloy sources is the scrap. However, old stocks of scrap must be exhausted, or almost exhausted, by now, and the scrap at present produced in the steel-making process must contain increasingly smaller percentages of alloying elements. Thus, the engineering steels produced in 1943 were, perhaps, virtually two-alloy steels. As will be seen later, the two-alloy pattern may be the only one possible for German steel composition in 1944. First, however, it may be fruitful to consider metallurgical analyses of captured German materiel, which throw some light on the properties and types of enemy steels.

## VII. CAPTURED MATERIEL

With a view to taking advantage of every useful feature of enemy ordnance, exhaustive examinations of captured materiel are carried out both in the United States and in Great Britain. Large stocks of enemy war equipment were taken in North Africa and Italy, and some of it has been subjected to metallurgical examination.

A study of the extent and meaning of any changes occurring in German alloy-steel products in the years 1939 through 1942 would provide an exact check on German practice in the use of ferro-alloys. Unfortunately, this is not possible at present. The main reason is that, with the exception of German armor plate analyzed by the British, not a single series of specimens--engine parts, armor plate, guns, or other ammunition--has been followed through all the years of the war. In fact, many examination reports do not mention the year of manufacture of the article studied. Moreover, the examinations are frequently of different parts of different products--here a fragment of an armor plate, there a gun barrel, or a projectile, a cartridge case, or a valve seat. Furthermore, according to present information, no weapons or other war materiel produced in 1943 have yet been analyzed. It is, therefore, impossible to make any comparison between identical metal products manufactured throughout the war years.

Under the circumstances, this report will simply summarize the few most important findings on German alloy steel obtained from the analyses of enemy equipment.

### Types of Enemy Steel in Armor Plate, Guns, and Shells

It has been found that captured ordnance parts made at the beginning of the war were mostly of chromium-molybdenum steel. This was, for instance, the type of steel used in the German tanks armor plate (mentioned above) examined by the British War Service, the only examination which permitted a comparison of a similar, if not identical, German product for the years 1940 through 1942. Throughout the entire period, the armor plate, both homogeneous and face-hardened, was made of chromium-molybdenum steel (see Table 13). The trifling amounts of nickel or vanadium shown may have represented residuals in the scrap used.

The British reported a shift from chromium-molybdenum steel to nickel-chromium steel in German tanks armor plate made in 1943. However, as no analysis was made of a specimen, it was not included in the table. This is the only report of such a shift. If it is true,





Germany would have needed 300 to 600 tons of nickel to manufacture nickel-chromium steel; these quantities may have been available in 1943, or the nickel content may have come from captured battlefield scrap, carefully segregated by the Germans.

The German A.P. shell and also gun steels were almost exclusively of the nickel-chromium-molybdenum type at the beginning of the war, as they are still in the United States and in Great Britain. A rather typical analysis of German ammunition of this period revealed 1.2 to 1.5 percent chromium, 0.2 to 0.3 percent molybdenum, and 0.3 to 0.4 percent nickel. Steel of some German gun barrels, such as that of the 7.5 cm. KwK tank gun, has been found to be of comparatively high alloy content: chromium 1.85 to 2.00 percent, nickel 1.2 to 1.5 percent, and vanadium 0.10 to 0.15 percent. Manganese content ranged between 0.5 and 0.8 percent.

Deviations from this standard type were found in gun steel. At the end of November, 1942, the percentage of chromium in such steel was reduced by .25 to .50 of one percent, that of nickel raised to 1.7 percent, and that of manganese raised from .80 to 2.00 percent. It is known that, at this time, German steel-works were ordered to report on savings achieved in chromium. The nickel content was assumed to have come from scrap.

No use of the scarcer alloys in high-explosive shells was disclosed by the examinations of captured materiel. For instance, 8.8 cm. shells manufactured late in the fall of 1942 contained only residual amounts of molybdenum, up to .6 percent of nickel, which may or may not have been residual, plus some vanadium and manganese. The 37 mm. high explosives showed only a trace of nickel and vanadium both in the nose and the body, 1.15 to 1.25 percent chromium, and 0.0 to 0.30 percent molybdenum.

The examination of German 7.9 cartridge link belts, showed them to be made of a type of stainless steel that was 18 percent manganese and 9.84 percent chromium. As this item was manufactured in 1939, it is worth noting as evidence of the German tendency to conserve the scarce materials, such as nickel, even at so early a date.

### Silicon-Manganese Steel

Examinations of German A.P. shell and 88 mm. ammunition steels manufactured late in 1942 are reported to reveal a change from the chromium-molybdenum type of steel to the silicon-manganese, a change

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TABLE 13

Ferro-Alloy Composition of German Tanks Armor Plate

| Type of plate; Period | Type of Tanks | Number of specimens | Range of analysis - percent C | Si | Mn | Ni | Cr | Mo | a/ V |
|---|---|---|---|---|---|---|---|---|---|
| Homogeneous Machineable 1940-41 | Pz.Kw.IV, Model D | 9 | 0.29- 0.35 | 0.27- 0.43 | 0.30- 0.41 | 0.04- 0.23 | 2.35- 2.59 | 0.34- 0.44 | Nil |
| 1941-42 | Pz.Kw.III, Various | 16 | 0.44- 0.56 | 0.24- 1.80 | 0.44- 0.80 | Trace 0.14 | 0.89- 1.51 | 0.25 0.60 | Nil to 0.19 |
| | Pz.Kw.III, Model J | 6 | 0.42- 0.51 | 0.70- 0.78 | 0.59- 0.72 | 0.09- 0.22 | 1.32- 1.53- | 0.41- 0.52 | Nil 0.19 |
| 1942 | Pz.Kw.VI. | 6 | 0.46- 0.52 | 0.28- 0.35 | 0.65- 0.72 | 0.02- 0.05 | 2.23- 2.64 | 0.52- 0.59 | Nil |
| Face-hardened 1940-41 | Pz.Kw.III, Model F | 4 | 0.24- 0.27 | 0.24- 0.64 | 0.96- 1.15 | 0.02- 0.13 | 0.91- 1.39 | 0.30- 0.39 | Nil Trace |
| 1941-42 | Pz.Kw.III -H | 4 | 0.15- 0.22 | 0.19- 0.25 | 0.22- 0.38 | 0.11- 0.19 | 2.51- 2.60 | 0.39- 0.46 | Nil to 0.02 |
| Flame-hardened 1942 | Pz.Kw.III -J | 10 | 0.42- 0.62 | 0.27- 0.78 | 0.56- 0.72 | Trace 0.38 | 1.23- 1.62 | 0.29- 0.66 | Nil to 0.26 |

Source: MEW, Intelligence Weekly, No. 95, December 2, 1943.

a/ The symbols, in order, stand for carbon, silicon, manganese, nickel, chromium, molybdenum, and vanadium.





that might logically have taken place as supplies of chromium and nickel dwindled. On the other hand, the analysis of German aircraft armor plate revealed a drift in the opposite direction. The armor plate of the earlier enemy bombers (the entirely obsolescent Dornier 17 and Heinkel 111 of 1935), as well as the fighters (Messerschmit 109 of 1936 and 1937), was made of steel containing from 1 to 2.25 percent silicon and up to 1.5 percent manganese, with high carbon content and no chromium. Current models, however, such as Messerschmit 109F of 1942 and Focke-Wulfe 190 of 1942-43, have armor plate made of either silicon-chromium-molybdenum steel or of plain 1.5 percent chromium steel. This represents an improvement in the type of steel used for armor plate, an improvement which, in the opinion of MEW, was forced upon Germany by the heavier caliber ammunition of the United Nations. As the requirements of chromium and molybdenum for the aircraft armor are small in themselves, as well as in comparison to amounts needed for other purposes, Germany is no doubt able to satisfy them. The reported shift to silicon-manganese steels in shells and ammunition, however, may mark the beginning of the use of this steel in other war materiel. Further manifestations of this shift would demonstrate a growing urgency on Germany's part to practice extreme economy in the use of the scarcer ferro-alloys.

The substitution possibilities of silicon are limited. Silicon has an alloy power of approximately the same magnitude as that of nickel. Most engineering steels in this country and also in Germany contain up to .30 percent silicon. This content may be increased up to one percent in as much as one-third of the steel, but beyond this point it cannot be applied efficiently.

No supply problem is involved in the application of silicon, because Germany has an excess capacity for producing this alloying element. Following the usual metallurgical practice in the use of silicon, Germany would require between 35,000 and 40,000 tons of silicon per year. As much as 100,000 tons of silicon can be produced annually within German-controlled territories excluding Norway, which, in addition, has a large capacity for silicon production. Norway is now producing ferro-silicon at the Electric Furnace Products Co. Ltd., at Sauda, the largest ferro-alloy plant in Europe. 5/

5/ This plant, which formerly turned out 60,000 tons of ferro-manganese annually, apparently cannot now be supplied by Germany with manganese ore for the production of this ferro-alloy.

Summary of Findings on Captured Materiel

The analyses of captured war materiel have not been sufficiently extensive to permit a careful check on German practice in the use of ferro-alloys. It is an established fact that the quality and workmanship of German materiel manufactured at the beginning of the war were excellent; in only a few cases could the evidence of shortage or severe economy be established. The enemy war equipment thus far examined has shown no deterioration in quality or effectiveness. Some of the analyses would seem to suggest that no shortage of ferro-alloys existed in Germany and that, in fact, no serious effort at economy in the use of these vital materiels had been made.

Certain observations, however,--the low nickel and chromium content of some of the steels, the high percentage of chromium and manganese in stainless steel, and the shifts toward stronger armor plate and a new silicon-manganese steel type--fit into the overall picture of ferro-alloys as presented in this report.





VIII. OUTLOOK FOR 1944

Germany entered this crucial year of the war with almost no stocks of any major ferro-alloy, with the possible exception of manganese. Of all the ferro-alloys important in steel-making, only vanadium might be produced domestically in adequate quantities, and even this is doubtful. To maintain its alloy steel economy--already reduced to a two-alloy pattern for engineering steels--Germany is dependent upon current supplies from the occupied or neutral countries of Europe. The liberation of occupied countries or a changing policy in neutral countries would cut the vital ferro-alloy supply lines and endanger the precarious two-alloy pattern of ordnance steels.

With territorial changes in Enemy Europe impending in 1944, the various alternatives possible for the German alloy steel economy should be examined.

Output of Steel in 1944

Since 1940, the theoretical steel capacity of Germany has been in the neighborhood of 52 million tons a year. However, many of the small steel plants have not been in operation. Some were dismantled to furnish the operating steel works with additional equipment. Labor shortages, the difficulty of transporting iron ore and ferro-alloys to numerous small plants dispersed throughout the country, and their need of new tools have reduced the output of others. Furthermore, many of the small plants that were operating may have been put out of commission by bombing, and bomb damage and destruction have been, and will continue to be, inflicted on many large plants. The steel capacity of Enemy Europe may now be as much as 10 to 20 percent lower than the theoretical figure. It has been estimated that actual production in 1943 was approximately 35 million tons.

The loss of Belgium, Luxembourg, and Northeastern France, and the interruption of deliveries of Swedish iron ore would have the most serious effect on Germany's total steel output in 1944. In 1943, Belgium, Luxembourg, and France supplied Germany with about 33 million tons of ore, averaging 33 percent iron content. Their steel works turned out from 8 to 9 million tons of steel (5.5 to 6 million tons in France and 2.5 to 3 million tons in Belgium and Luxembourg). They have an additional capacity of about 5 to 6 million tons of steel a year.

For the entire period of the war, Sweden has exported to Germany about 9 million tons of iron ore annually. Swedish ore--which is high grade and contains little phosphorus--is of extreme importance to the German steel economy. Sweden has agreed to limit its exports to Enemy Europe to 7.5 million tons in 1944.

If Germany is forced to withdraw from France, Belgium, and Luxembourg, it will lose the large supplies of iron ore and the steel made in these countries on German account. As a result, the German annual steel output will decline about 25 percent. Should Sweden either be cut off from Germany or voluntarily stop the shipments of iron ore, reduction by perhaps another 25 percent is to be expected.

Germany would have to distribute a diminishing steel output among different steel products. As a result of shortened lines of communication, caused by the retreat from the USSR and Italy, Germany may decide to stop the construction of railway cars or locomotives and thus eliminate from its steel program one of the largest steel-consuming items (see Table 5). It is equally probable that Germany will greatly reduce, if not terminate altogether, allocations of steel for plant construction work, for agricultural machinery and perhaps for the shipbuilding program. It may go even beyond this: Should Germany be shown the hopelessness of the underwater attacks on the United Nations' ships, the submarine program might be reduced. If the value of tanks for defensive fighting becomes questionable, the output of these might similarly be curtailed. Cutting to the bone every demand for steel which may not have a very serious bearing on the war program in 1944, Germany probably will give high priority rating to military materiel and will go on producing ammunition, tanks, and airplanes. The Germans may even increase the production of ammunition and of planes to protect the sky over their "roofless fortress".

Thus, Germany's defensive warfare may not be affected if, in 1944, its plants turn out not 35, but 30 or even 25, million tons of steel. What will matter is that Germany may still be capable of maintaining a comparatively high level of alloy steel production and probably will maintain this production at the expense of heavy cuts in carbon steel output. Even if Germany is forced to withdraw within prewar frontiers and to return to a steel output of 18 to 20 million tons a year, it may still continue to manufacture war materiel on only a slightly reduced scale, and the German alloy-steel output in 1944 may be about the same as in 1943 or only slightly smaller.





## Supplies of Ferro-Alloys in 1944

The factor of ferro-alloy supplies is certain to play an important role in Germany's steel economy during 1944. This is true of one alloying element in particular, manganese, which is as indispensable in steel-making as is yeast in making bread. The loss of Nikopol, Germany's main source of current manganese supplies, can be expected in the near future. When this occurs, Germany will be forced to make every possible effort to increase the production of manganese from domestic manganiferous ores. Because the manganese content of these ores is very low, they have always been considered as a supplementary, and not the basic, source of this metal. Yet, as explained before, there are expansion possibilities which will certainly be exploited, if they have not been already in anticipation of the fall of Nikopol. However, it is believed that this supply can not become of major importance.

At the beginning of 1944, Germany possibly had about 90,000 tons of contained manganese in stock and may have increased, to some extent, the output of plants within areas under German control. The total supplies of manganese metal, therefore, may amount to 220,000 or 230,000 tons, which would probably satisfy the 1944 requirements, if the total steel output is reduced to 25 or 30 million tons and the position in other ferro-alloys remains at the 1943 level.

The transportation advantages accruing from the control of continental resources throughout the war may be lost in 1944. With bombing on an ever-increasing scale, numerous interruptions are bound to occur at many points. Plants having to wait for iron ore to arrive from Sweden via Stettin or other raided ports, for nickel to come from Finland, or for chrome from Yugoslavia or Turkey, can hardly avoid stoppages in work.

More important, however, direct military action as well as economic warfare measures may cut off the sources of ferro-alloy supplies.

<u>Supplies from the Balkans and Turkey</u>. The loss of the Balkans would cut off Germany from its principal source of chrome ore.

As previously noted, Germany has shifted, or is on the verge of shifting, to a two-alloy steel pattern, based on chromium and manganese. With only insignificant stocks of chromium and meager reserves in the pipe-line, the equilibrium of the German alloy steel

economy is dependent on adequate current supplies. Should Germany be barred from the mines of Yugoslavia, Greece, and Albania, and also lose the chrome imports from Turkey, the two-pattern system of making engineering steels would be seriously endangered. If all sources of chrome are closed, Germany will not be able to restore the balance in its ordnance steels, no matter how well provided it may be with manganese, how efficient it is in recovering every possible ton of chrome or nickel from scrap, or how much it may expand the production of vanadium. Thus, the reoccupation of the Balkans and the cutting of Turkish chrome supplies would most seriously affect the output of ordnance steels in Germany.

In addition, German current supplies of nickel will be reduced by about 12 to 15 percent when Greece is liberated.

These losses in conjunction with the loss of manganese from Nikopol, would place the German alloy steel economy in a truly hopeless situation.

Supplies from Norway and Finland. The loss of Norway would cost Germany at least half of its current supplies of molybdenum, and approximately 12 to 15 percent of its supplies of nickel.

Should Finland withdraw from hostilities against the USSR or be forced to cease shipments of nickel to Germany, or should the Petsamo smelter be destroyed by bombing, the current nickel supplies to Germany would be reduced by about 50 percent. The production of stainless steels would, in this event, have to be drastically curtailed. In fact, the production of stainless steels may become impossible if nickel supplies from the North and chrome supplies from the Southeast are cut simultaneously.

Supplies from the Iberian Peninsula. Tungsten, the all-important ferro-alloy for high-speed steels and carbide tools, is still supplied in sufficient quantities by Spain and Portugal to meet Germany's minimum industrial requirements. By the preemption of substantial amounts of tungsten ore in these countries, the United Nations may have prevented Germany from building up a large stockpile for an emergency, but they have been unable to deprive it of the quantities needed to meet current industrial requirements. German domestic output of tungsten, about 200 tons a year, amounts to only five percent of current supplies ~~dupplies~~. If tungsten supplies from the Iberian Peninsula were cut off, the production of high-speed steels and carbide tools would be interrupted. While this would be a severe blow to the German tooling system, its effect would not be immediately apparent, because Germany could probably get along for another year with the tools it has.





Lag Factor and Pipe-Line Reserves Favoring Germany in 1944

The difficulties that Germany will encounter if current supplies of ferro-alloys are cut off may not fully materialize in 1944 because of the lag factor.

As the war situation becomes critical, Germany may well take advantage of the long lag existing between the time when shipments of foreign ores cross the German frontier and the time when the finished steel product, such as the armor tank plate, or the engine of the aircraft, actually reaches the battleline. It takes about one week for a carload of chrome or manganese ore at the German border to reach the loading platform of the furnace of a ferro-alloy plant, and about ten days (formerly three weeks) for the ore to go through that plant. Three to four days are required for shipping the product from the ferro-alloy plant to the steel furnace, and an additional five weeks, on the average, for completion of the ingot. The whole process can be rushed through in eight weeks, although, in peacetime, it took about six months. To maintain this high-speed in steel-making and manufacturing processes, there must be no interruption at any point of the line; transportation must function perfectly, plants operate on schedule, etc. Whether such conditions can be achieved in Germany under continuous air bombardment is questionable. It would appear that three months rather than eight weeks would be a reasonable estimate of the lag from the time the ore leaves the German border until it appears in ingot form.

The production of ingots, however, is only the first step. The ingot goes to a manufacturing plant where it is used in the making of an engine, a plate, or a shell. There are many time-consuming stages in the manufacturing process--shaping, testing, assembling of various parts, registering, loading, etc. When the steel product for the armed forces has been finished, it is shipped to the proving-ground, then loaded again and transported to behind-the-line depots. There it is either stored and later shipped, or immediately loaded and moved to the battle area. Registrations, checking, or changing the destination also require time. On the whole, it is a safe assumption that about three months pass before a steel ingot reaches the actual battlefront in the form of a finished product, raising the total lag to about six months.

The significance of the lag factor is that Germany's loss of vital ferro-alloy supplies will not become apparent in the quality of war materiel in use on the battlefields until 6 to 9 months after the supplies are cut off. Should Germany lose the Balkans or

the countries of Western Europe early in 1944, it may still have available throughout the latter part of the year war materiel of the same quantity and quality as in 1943.

Germany will have on its side in this last phase of the war not only the lag factor, but also the pipe-line reserves, i.e., those materials in process of transport and manufacture and those stocks necessary to insure continuous production of a plant. Although the Germans have husbanded their supplies of ferro-alloys throughout the war, at this stage they are likely to adopt a policy of throwing everything into the balance on the 1944 battlefronts. They may be expected to use up all available reserves, every particle from their pipe-lines. Such reserves in every plant may amount to supplies for a few weeks, a month, or more. The opportunity of squeezing out the last driblet on a continental scale may thus delay by several months the breakdown of Germany's ferro-alloy economy. Should, however, important areas be lost this year and the war be prolonged into 1945, the German alloy steel economy will face complete collapse.

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TITLE